The Bell System Technical Journal
Safeguard Supplement
Printed in U.S.A.

SAFEGUARD Data-Processing System:

Foreword

The U.S. government needs and obtains a wide range of services from the nation's businesses. From the Bell System, these services range from the large amounts of ordinary telephone service required to carry on its day-to-day operations to the development of complex systems designed to ensure the nation's defense. With respect to the latter, Bell System policy is summarized in a remark by H. I. Romnes at a stockholders' meeting on April 15, 1970:

> "The Bell System engages in military work as a responsibility we owe our country. We make available some of the communications expertise of the Bell Telephone Laboratories and the Western Electric Company to carry out programs for which responsible agencies of the government have a defined need. We did not seek out military work nor do we seek to expand the amount we have."

The largest system development ever carried out for the Department of Defense by the Bell System started with some exploratory research and development work in 1957 and culminated with the completion of installation and testing of the Safeguard Ballistic Missile Defense System in early 1975. Western Electric was the prime contractor for the Safeguard system and Bell Laboratories was responsible for the design. Major subcontractors were Raytheon and General Electric for the radars, Martin Marietta and McDonnell Douglas for the missiles, and Univac and IBM for the data-processing system.

Safeguard may be the most complex system ever produced by a single, integrated, research and development project and the system would take many volumes to describe. The overall design required the solution of many complex technical problems, and the major subsystems—the two radars, the two missiles, data processing, command and control, and communications—are lengthy stories in themselves. However, the data-processing subsystem development probably has the greatest relevance to the Bell System. This is so because more and more systems are organized around a stored-program, general-purpose

computer, controlling system operation on a real-time basis. SAFEGUARD is an extraordinarily large system of this type. It provides a sort of upper bound for the other developments in many ways. For that reason, this supplement to The Bell System Technical Journal consists of papers that describe the major issues arising in the development of the data-processing subsystem, with emphasis on the software. The material included is limited to that which is felt to be useful to the general computing community, *and is an attempt to describe the lessons learned rather than just the successes.* As a result, other system developers may be helped in identifying some management techniques and technical approaches to avoid as well as those that might be useful to them.

To restrict this supplement to a manageable size, the level of detail had to be restricted. The papers are highly interdependent and are intended to be read as a group. Although many details of the design and development are not treated here, the volume as a whole provides a comprehensive summary of the pragmatic approach required for a highly schedule-sensitive project.

The volume begins with an introduction and overview paper. This paper provides important background material for all the other papers, including not only the general organization of the data-processing system but also the role of the data processor in the overall system and a brief history of the ABM system.

The remaining papers are organized into six sections, each covering a major facet of the effort. The Systems Engineering section consists of one paper that discusses the generation and control of requirements. Fundamental control of the entire software development was achieved through the Data Processing System Performance Requirements discussed in this paper.

The Hardware section contains papers describing the data-processing system architecture, emphasizing the modular nature of the system and the maintenance and diagnostic techniques that were important parts of the strategy for obtaining high availability.

The Real-Time Software Development section contains the description of those aspects of the design that depend most critically on the real-time nature of the application and the multiprocessor computer. The successful use of a pool of identical processors to provide the total required processing capacity was one of the major features of the project, and these papers summarize the impact of this system characteristic on the design of the operating system and the overall structure of the software. In particular, the techniques used to structure the software to make the most efficient use of all processors are described in the paper entitled "Process Design: The Structure of Real-Time

Software Systems." Other papers in this section describe the facilities and techniques used to test and debug the system.

The Support Systems section discusses those facilities that were of major importance in supporting the development of the real-time software. The overview paper which introduces this section provides a critical examination of some key decisions in establishing the support environment, which is necessary to every software development. As a result, this paper, and the other papers in this section, should be particularly relevant to other such efforts.

The Development Tools and Techniques section contains two papers that describe special techniques that were used to improve programming efficiency. Although it was not possible to gather enough data to establish unequivocal efficiency improvements, the results are interesting enough to warrant consideration on other projects.

The final section, Project Control, describes some of the more important techniques used throughout the project to monitor progress and maintain control. Although no panaceas were found for any of the well-known problems of controlling software developments, the successful completion of the project demonstrates that adequate techniques are available. Since industry-wide experience indicates that many large software developments in the past have had as much trouble with general project control as with the technical aspects of design, the discussion of the variety of project control techniques used and their effectiveness is believed to be important.

It is impossible in a brief description of a large system development to find any adequate way to acknowledge the contributions of everyone involved. In addition to the major subcontractors listed earlier, important contributions were made by a large number of other organizations. Although all the authors were major participants in the activities which they have documented, many other individuals made contributions equally important. Each of the over two thousand people involved during the course of the project made real contributions toward its success, and it is not possible to acknowledge individually here the very large number of these who provided the key technical and managerial innovations that were vital to that success.

Thomas H. Crowley
Executive Director
Safeguard Design Division